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UNSTEADY EFFECTS OF CIRCUMFERENTIAL PRESSURE DISTORTED INLET FL--ETC(U)
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CRANFIELD INSTITUTE OF TECHNOLOGY

SECOND PROGRESS REPORT

PREPARED FOR

UNITED STATES AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFSC) USA

EUROPEAN OFFICE OF AEROSAPCE RESEARCH AND DEVELOPMENT,

LONDON, GREAT BRITAIN

UNSTEADY EFFECTS OF CIRCUMFERENTIAL PRESSURE DISTORTED INLET FLOWS IN COMPRESSORS

GRANT AFOSR 77-3305

(061392)

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1.0 INTRODUCTION

Interest in the performance penalties incurred in installed aero-gas turbine engines when subjected to inlet flow distortions and flow unsteadiness has stimulated interest for some time. An understanding of the basic physics involved in the fluid flow under such conditions would clearly be an excellent foundation upon which to base remedial measures to eliminate or at least diminish the reduced performance. Several mathematical models have been proposed to describe either the overall behaviour of the compressor in terms of recognisable overall performance parameters or to simulate the flow around individual aerofoils, the basic components of a compressor. All known models have however stopped short of attempting a full description of the detailed transient flow conditions within the compressor, because not only has this represented a formidable mathematical challenge but the flow mechanics has not been mapped or understood.

In order to measure the unsteady flows in a compressor, it is clearly necessary to develop high response instrumentation and because of interest that must focus on the rotor row it may be deemed desirable to mount such instrumentation if possible, on the rotor. It may also be recognised that the efficient use of a high response instrumentation system also calls for an efficient high speed data acquisition and analysis system.

It was that unsteady measurements should be possible on rotor blades that a rotor-borne system was devised and developed at Cranfield. Much of the development work was executed under the research grant AFOSR-74-2708 and data were presented in the final report of that contract. A subsequent grant AFOSR-77-3305 formed a logical sequence, but included the development of an improved peripheral system. This report, the second progress report describes the system in some detail.

2.0 OBJECTIVE

The overall long-term aim of the Cranfield research programme is to produce:-

1. an improved parameter for quantifying distortion
2. improvements in performance prediction techniques for compressors in quasi-steady distorted flows
3. a prediction technique for compressors in pulsating flows
4. a design method that will reduce compressor sensitivity to inlet flow distortions.

This involves an integrated programme of research in which five experimental rigs are being used. In parallel, mathematical models of distorted flows and compressor reactions to them are under development.

The detailed aim of that part of the programme covered by the research grant AFOSR-77-3305 may be quantified as:

1. the development of a custom-designed data acquisition and analysis system
2. evaluation of rotating stall phenomena
3. evaluation of distortion on rotor transients and compressor behaviour
4. flow modelling

3.0 THE ROTOR-BORNE MEASURING SYSTEM

3.1 Requirements

The basic requirements of a rotor-borne system are that mechanical integrity and calibrations will be maintained under high 'g' conditions and that the frequency response will be sensibly higher than the disturbance frequency in the flow: (In the application to be discussed 'g' loads of up to 800 and disturbance frequencies of 25 Hz. could be encountered.)

With an analogue output from the rotor-borne system it is also necessary to have a comprehensive peripheral data recording and analysis system. To achieve this it is necessary to be able to

1. record many channels simultaneously
2. detect any non-synchronous data, such as rotating stall
3. detect non-periodic data
4. record in real time

3.2 The Rotor-Borne Components

Since the unsteady pressures around the compressor blades are a good indication of the flow field behaviour it is necessary to mount pressure transducers on the rotor assembly. Compactness, low weight, mechanical integrity, shock resistance, good frequency response with high natural frequency, low hysteresis characteristic, high resolution, temperature and acceleration insensitivity are characteristics of a good transducer for this application. Of those examined a miniature silicon diaphragm with a fully active wheatstone bridge has been selected.

3.3 Installation

The high natural frequency of such a transducer can only be exploited if the diaphragm is directly exposed to the unsteady pressure. For compressor blades this would call for surface mounting that would destroy the blade contour, so a buried system is adopted and an accompanying reduction in natural frequency of the system accepted. The pressure amplitude ratio, that of sensed pressure (P_2) to forcing pressure (P_1) and the phase-lag has been theoretically evaluated by Bergh and Tijdeman (ref. 1) and simplified by Schweikhard (ref. 2) to yield:

amplitude ratio $\frac{P_2}{P_1} = \frac{1}{\sqrt{1 - \left(\frac{\omega}{\omega_n}\right)^{2\;2} + \left(\frac{2\zeta\omega}{\omega_n}\right)^2}}$

phase angle $\phi = \mathrm{Tan}^{-1} \cdot \frac{2\zeta}{\left(\frac{\omega}{\omega_n} - \frac{\omega_n}{\omega}\right)}$

(ω is frequency of fluctuating pressure)

where the damping ratio $\zeta = \frac{4\nu}{r^3} \cdot \sqrt{\frac{L}{\pi}\left(\frac{\rho}{\gamma P}\right)\left(V + \frac{4r^2L}{\pi}\right)}$

and the natural frequency: $\omega_n = \sqrt{\frac{\gamma P}{\rho} \frac{r^2}{4\pi L\left(V + \frac{4r^2L}{\pi}\right)}}$

(γ is the ratio of specific heats, P and ρ are mean air pressure and density respectively).

Typical results for a blade-mounted transducer system remote from the static pressure tapping (fig.1) are given in figs. 2 and 3.

During installation every effort is made to keep r as large as possible and V as small as possible in order to minimise response problems.

For a system with the transducer mounted in the blade adjacent to the tapping, the natural frequency becomes very high and beyond the range of concern.

3.4 The Effect of Centrifugal Force

The mass of the transducer diaphragm responds, for blade-mounted transducers in the installation considered, in the following manner to centrifugal force.

Rotational Speed rev./min.	g	% error F.S.
750	120	0.24
1000	213	0.43
1250	333	0.67
1500	479	0.96

For a transducer of full scale deflection pressure of 5 lb/in^2 the maximum error is 0.0479 lb/in^2.

With a blade mounted transducer system the transducer is connected to the static pressure tapping by a short pneumatic tube. The effect of centrifugal force on the volume of air is zero.

3.5 Rotor-Borne Signal Conditioning

The transducer signal passes through a 24-way slip ring, with a multiplexing system permitting up to 10 signals out of 20 to be carried simultaneously. Good signal-to-noise ratio is achieved using a high quality slip-ring assembly. Signal conditioning for thermal stability is carried out on-rotor.

3.6 The Peripheral Equipment

Signal amplification occurs in the stationary frame using specially designed amplifiers. The data (if time invarient) may be recorded on an oscilloscope or digital volt-meter, while a U.V. strip recorder may be used for a permanent time-variant analogue signal recording.

The latest standard of instrumentation however, includes a data reduction and storage system which includes an analogue-to-digital converter, a 16 K micro-processor, visual display unit, a digital-to-analogue converter and a cartridge record/playback unit (fig.4).

3.6.1 Analogue to digital converter

Analogue signals from the amplifiers are digitised in a 10 channel converter incorporating 10 individual ADC's for maximum digitising efficiency. Digitised data are passed immediately into the micro-processor for storage.

3.6.2 Microprocessor

The microprocessor is a 10 channel input model with a working store of 16K and capable of handling data up to a rate of 3kHz. This means that at a (maximum) compressor speed of 1666 r.p.m. recording could take place at 5^o intervals for over 22 consecutive cycles when utilising all the channels simultaneously. While, at slower compressor rotational speeds, recordings could be made at even smaller angular intervals (e.g. 3^o at 1000 r.p.m), in practice the microprocessor is triggered from the compressor shaft and will 'read' at 5^o intervals throughout the compressor speed range.

The logging capacity can easily be extended up to 64k if desired.

An additional ensemble averaged cycle is generated internally for subsequent data analysis.

3.6.3 Visual display unit/keyboard

Functional control of the microprocessor is based in a returnable "menu" system - various executive options are displayed on the VDU any one of which may be selected via the keyboard. This leads to a flexible system permitting, for example, the replay of data and manual inclusion of data.

3.6.4 Digital-to-analogue converters

Two DAC's are linked to the microprocessor and enable stored data to be displayed in analogue form for monitoring or signal comparison purposes.

3.6.5 Record/playback cartridge unit

This unit provides for permanent recording in "hard" form of the data stores in the microprocessor.

4.0 PROGRESS POSITION

Major hold-ups in supply of certain components have delayed final assembly of the system, but this has now been rectified. The completed peripheral systems has now entered its commissioning trials prior to its use in the programme.

5.0 CONCLUSIONS

In order to gain an understanding of the physics of unsteady flow in compressor rotating assemblies a new standard of instrumentation has been devised. The significant features may be summarised:

a) Engineering development of a rotor pressure measurement using micro-miniature pressure transducers to a high degree of accuracy.

b) The development around a microprocessor unit of a peripheral recording and data handling unit permitting rapid storage and analysis of data with the flexibility either to analyse data in real-time or to store for remote subsequent analysis on a separate computer facility.

Upon completion of the commissioning the instrumentation will be used in the proposed experimental programme.

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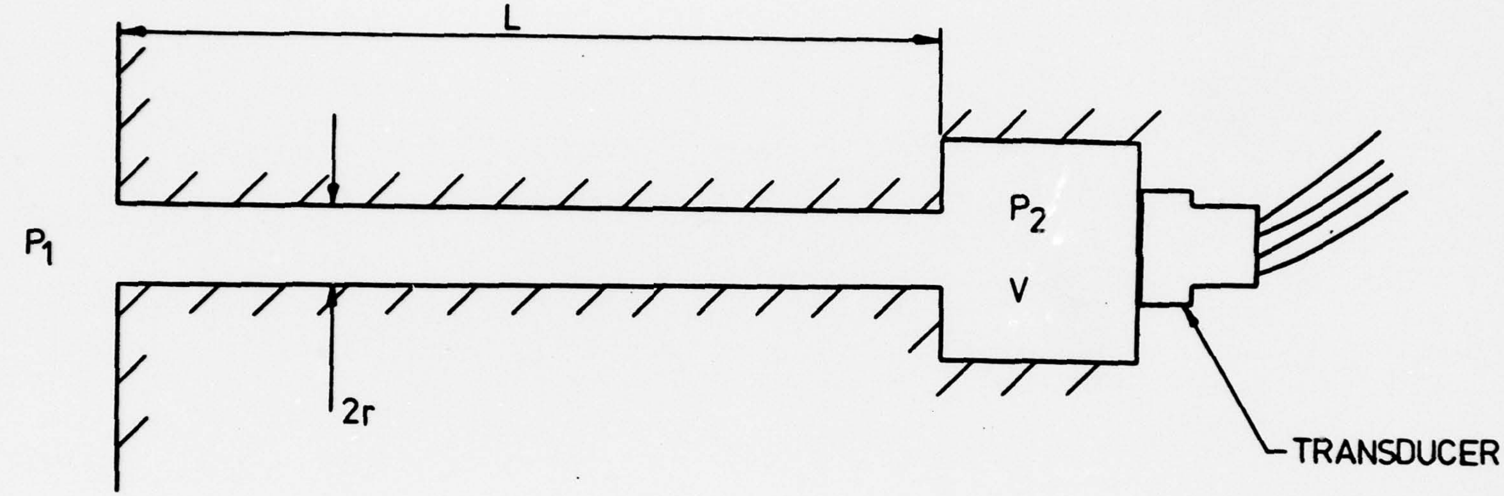
   W.G. Schweikhard
   AGARD - LS - 72 Distortion Induced Engine Instability (Nov.1974)



SIMPLIFIED TRANSDUCER / PIPE SYSTEM FOR FREQUENCY RESPONSE EVALUATION

FIG. 1

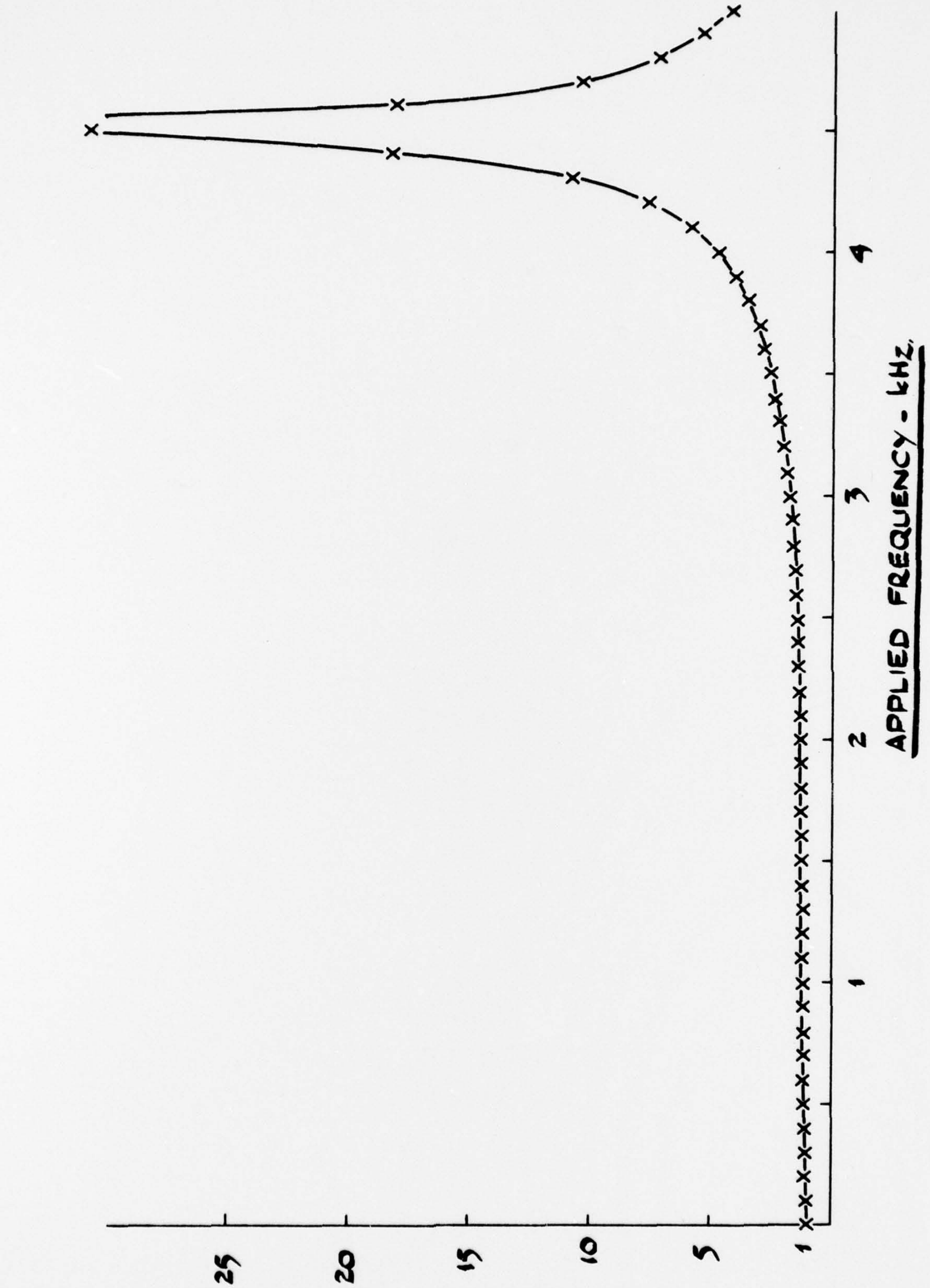


FIG. 2

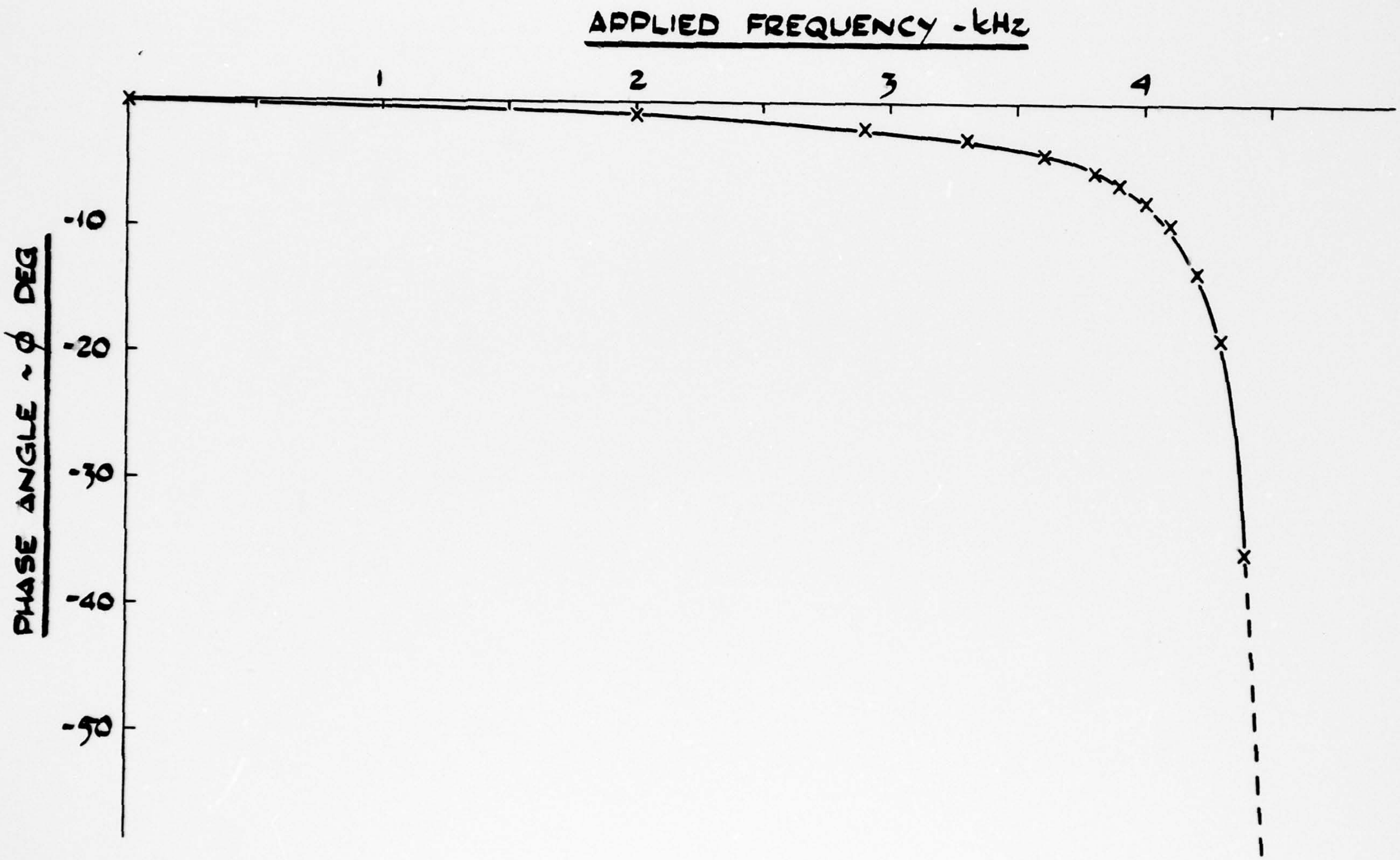


FIG 3

DATA RECORDING SYSTEM

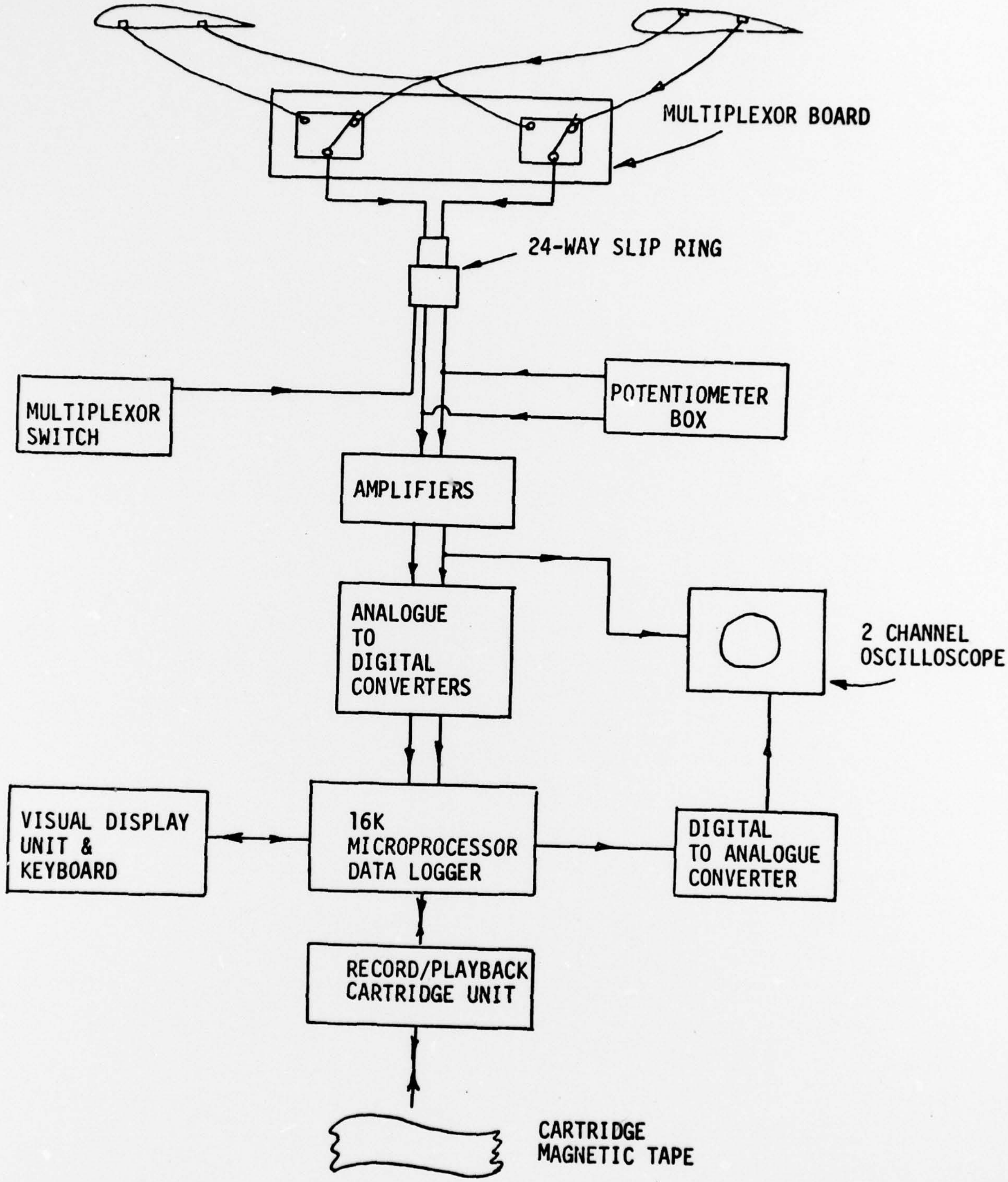


FIG. 4

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A high response measuring and data acquisition system is described which has been custom designed and built for the research facility used in this investigation. The system included the potential for measuring instantaneous dynamic pressures on rotor blades in unsteady flow and the real-time anslysis of data or alternatively data storage for off-line analysis.

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